eRHIC accelerator design and plans

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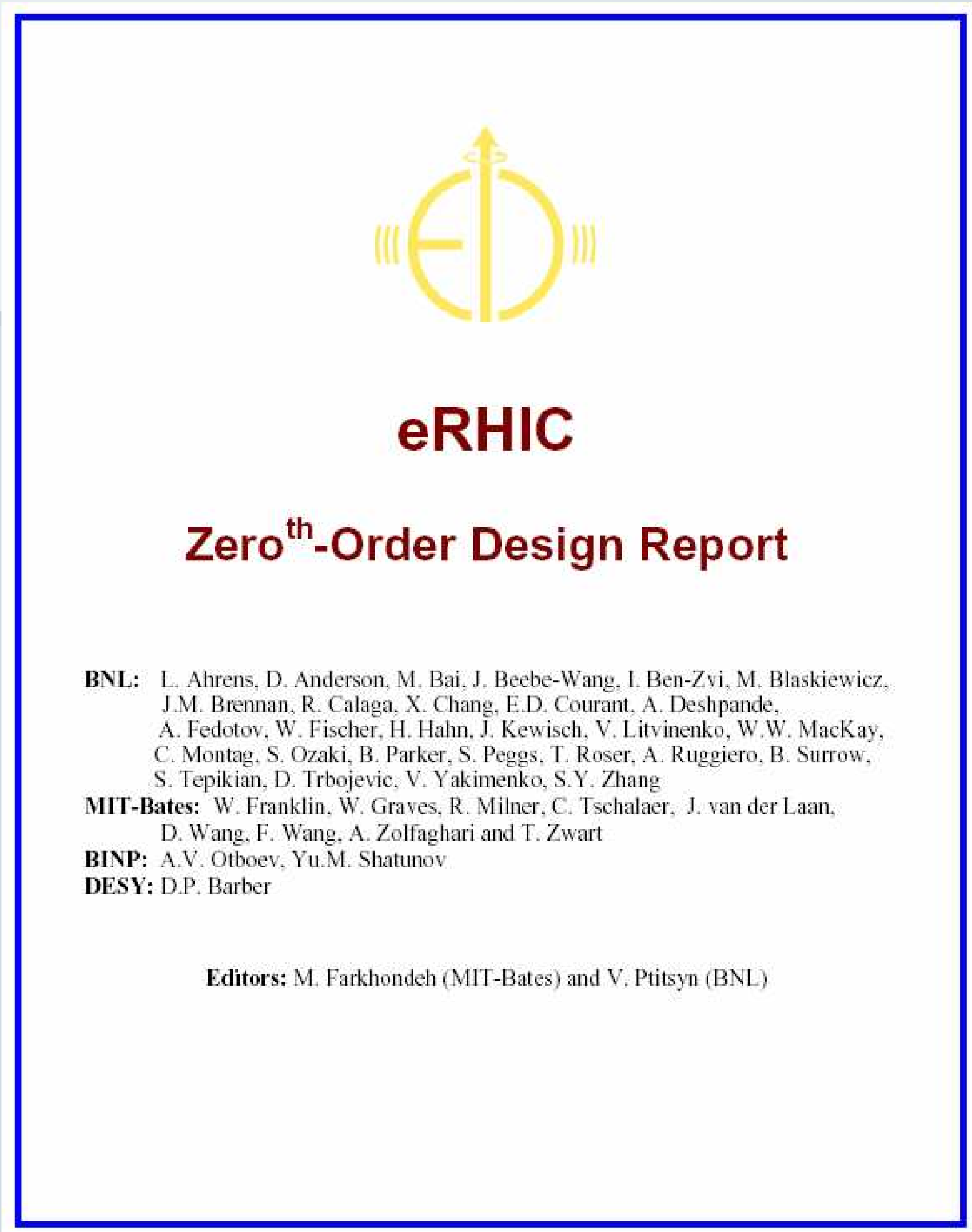


eRHIC

Zeroth-Order Design Report

BNL: L. Ahrens, D. Anderson, M. Bai, J. Beebe-Wang, I. Ben-Zvi, M. Blaskiewicz, J.M. Brennan, R. Calaga, X. Chang, E.D. Courant, A. Deshpande, A. Fedotov, W. Fischer, H. Hahn, J. Kewisch, V. Litvinenko, W.W. MacKay, C. Montag, S. Ozaki, B. Parker, S. Peggs, T. Roser, A. Ruggiero, B. Surrow, S. Tepikian, D. Trbojevic, V. Yakimenko, S.Y. Zhang
MIT-Bates: W. Franklin, W. Graves, R. Milner, C. Tschalaer, J. van der Laan, D. Wang, F. Wang, A. Zolfaghari and T. Zwart
BINP: A.V. Otboev, Yu.M. Shatunov
DESY: D.P. Barber

Editors: M. Farkhondeh (MIT-Bates) and V. Ptitsyn (BNL)

- Detailed document (265 pages) reporting studies on the accelerator and the interaction region of this future collider.
- The work performed jointly by BNL and MIT-Bates, with close collaboration with scientists from BINP (Novosibirsk) and DESY (Hamburg).
- Goals:
  - to develop an initial design for eRHIC
  - to investigate most important accelerator physics issues
  - to evaluate the luminosities that could be achieved in such a collider

The report web links:

1) www.agsrhichome.bnl.gov/AP/ap_notes/ap_note_142.pdf
2) www.agsrhichome.bnl.gov/eRHIC/eRHIC_ZDR.htm

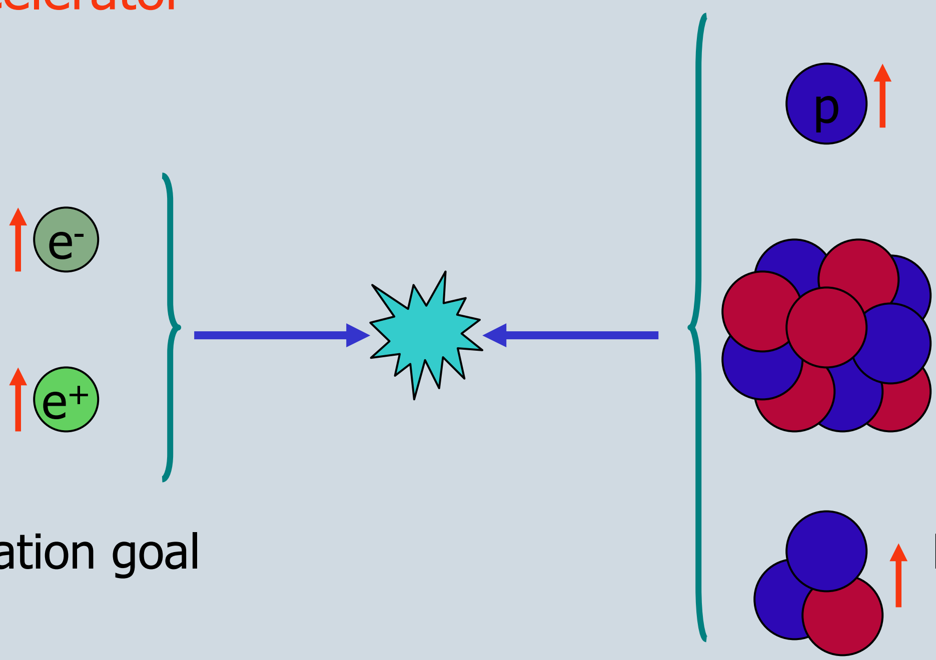
The present efforts are towards conceptual design development.

eRHIC Scope

Electron accelerator

RHIC

Polarized leptons
5-10 Gev



Polarized protons
50-250 Gev

Heavy ions (Au)
100 Gev/u

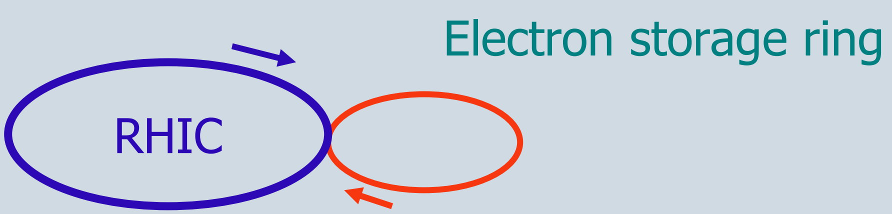
Polarized light ions (He^3)
167 Gev/u

70% beam polarization goal

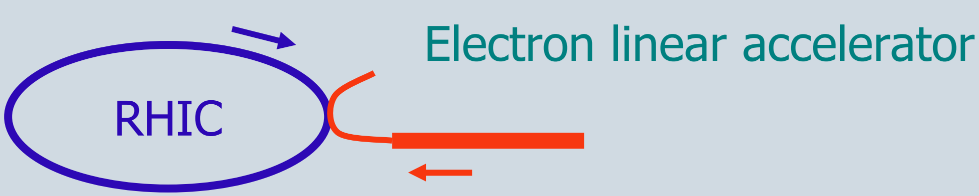
Center mass energy range: 30-100 Gev

How eRHIC can be realized?

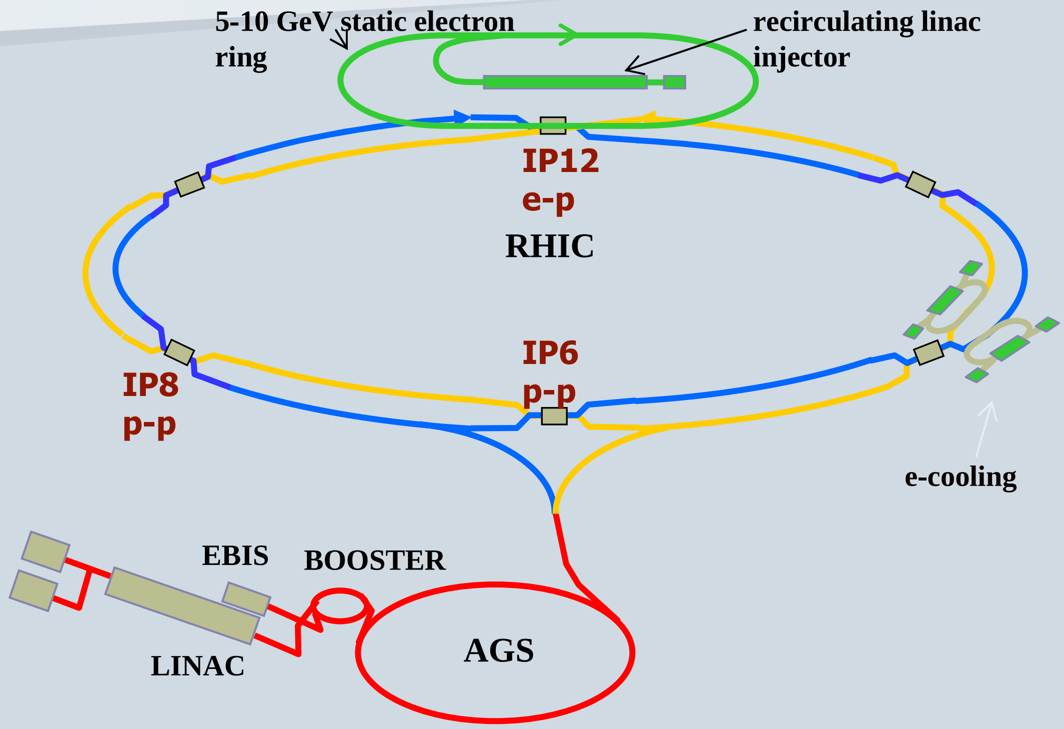
- Two main design options:
  - Ring-ring:



  - Linac-ring:



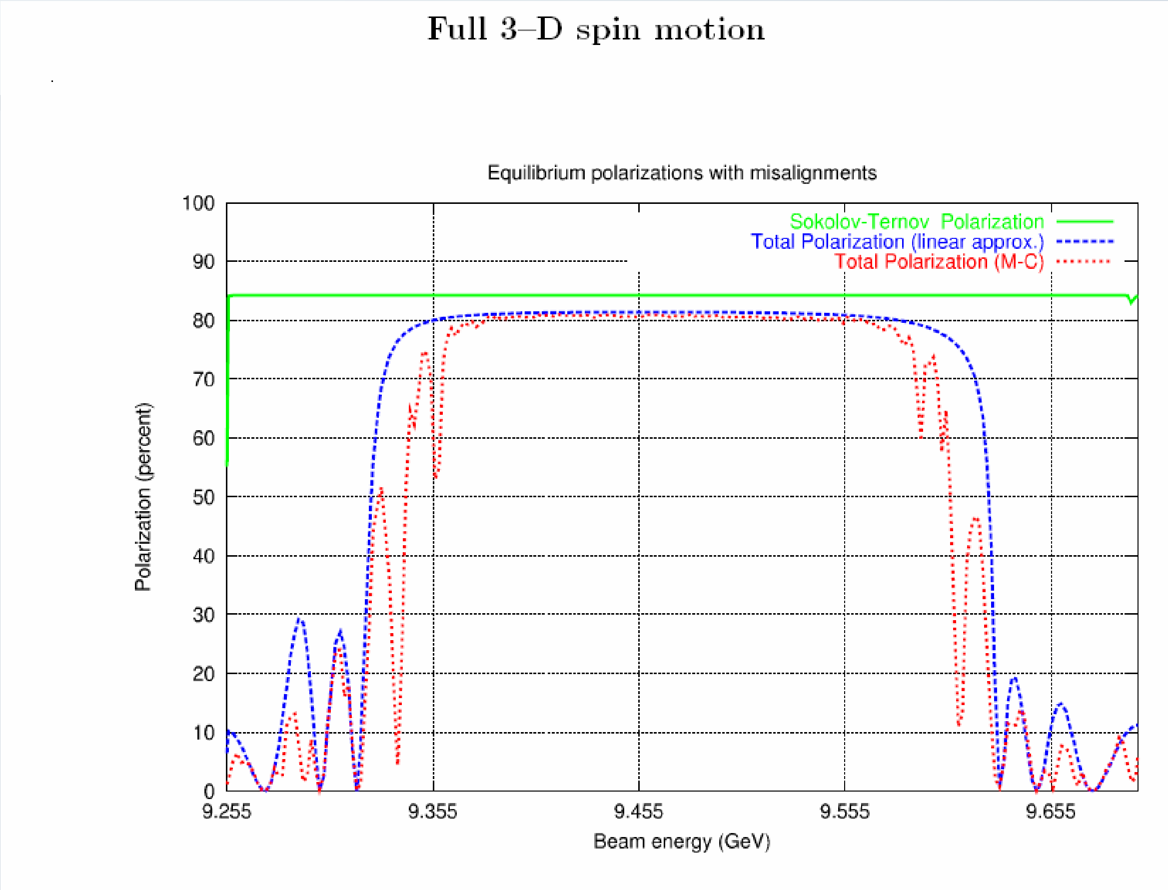
Ring-ring design option



- The electron ring of 1/3 of the RHIC ion ring circumference
- Full energy injection using polarized electron source and 10 GeV energy linac.
- e-ion collisions in one interaction point.
  (Parallel mode : Ion-ion collisions in IP6 and IP8 at the same time are possible.)
- Longitudinal polarization produced by local spin rotators in interaction regions.
- ZDR design luminosities (for high energy setup):
  - e-p: 4.4 10^{32} $cm^{-2}s^{-1}$
  - e-Au: 4.4 10^{30} $cm^{-2}s^{-1}$
  - e-He^3: 3.1 10^{32} $cm^{-2}s^{-1}$

The e-ring design development led by MIT-Bates.
Technology similar to used at B-factories.
Presently main design option.

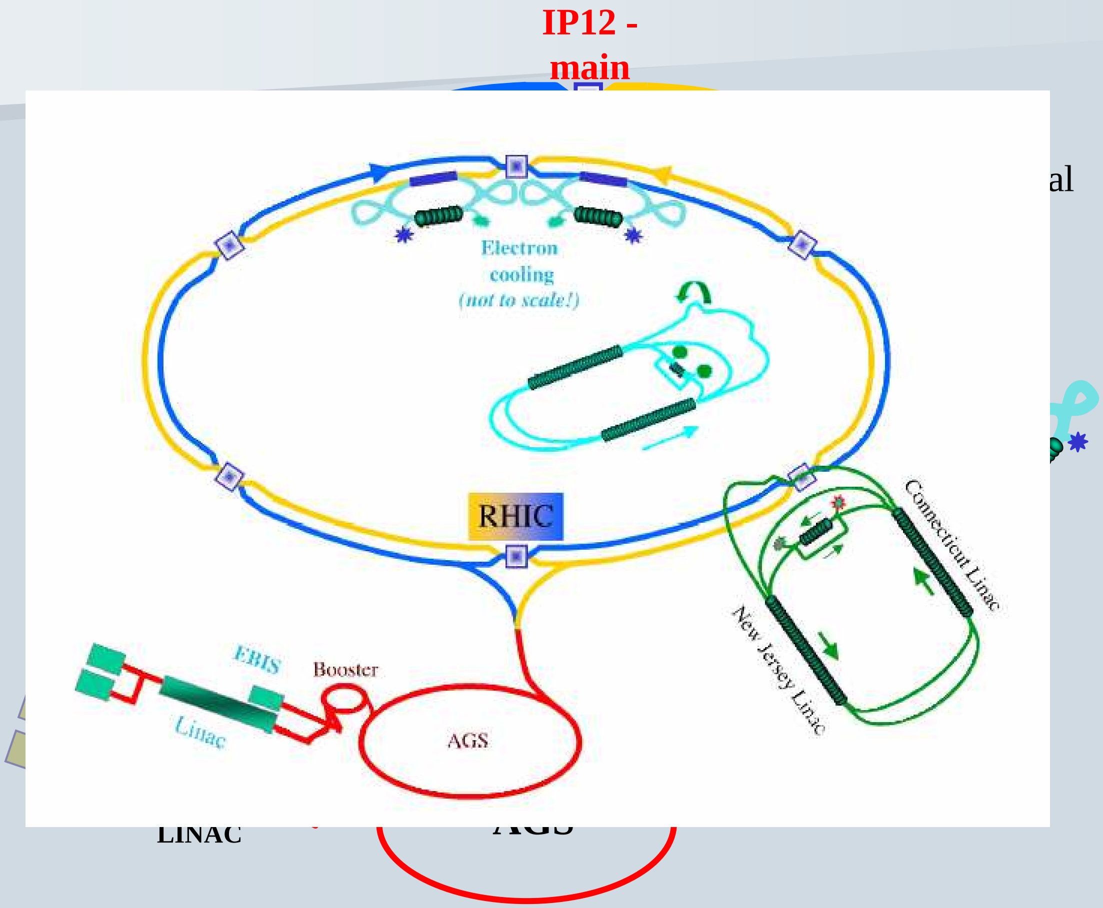
Electron polarization



D.Barber

- First results for high order calculation of electron polarization indicate wide enough energy range without strong depolarization resonances.
- Open issues:
  - Compensation of depolarization from detector solenoid
  - Possible depolarization from beam-beam effects

Linac-ring design

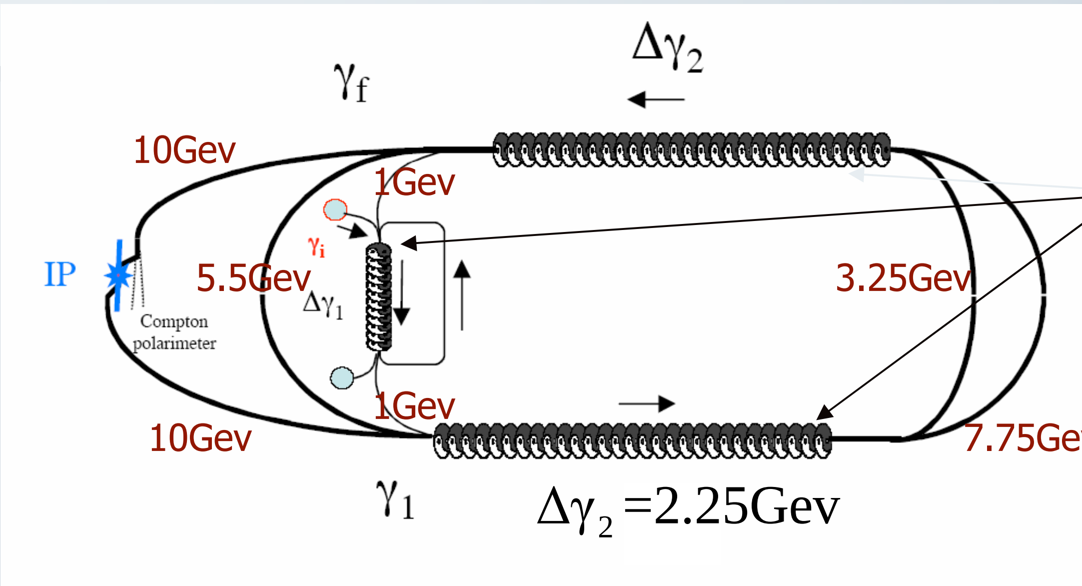


Design being developed at BNL
(ZDR: V.Litvinenko et al.)

- Electron beam is transported to collision point(s) directly from **superconducting energy recovery linac (ERL).**
- No beam-beam limitation for electron beam (the beam is used once!).
- No prohibited energy areas for the polarization.
- No spin rotators needed.
- e-p luminosity >10^{33} $cm^{-2}s^{-1}$ possible

- But no straightforward way to get polarized positrons

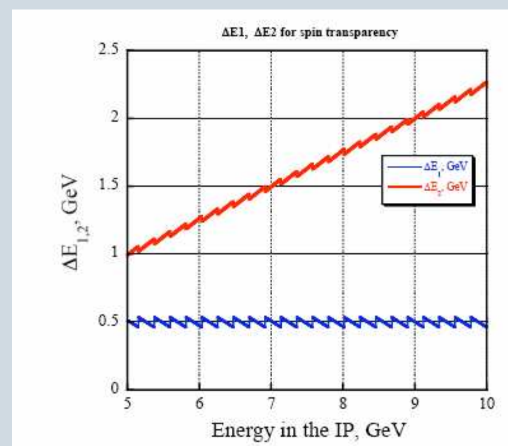
Energy-Recovery Linac



Multipass energy recovery linacs

Total beam power: up to 5MW

Superconducting technology is used for linac RF cavitites



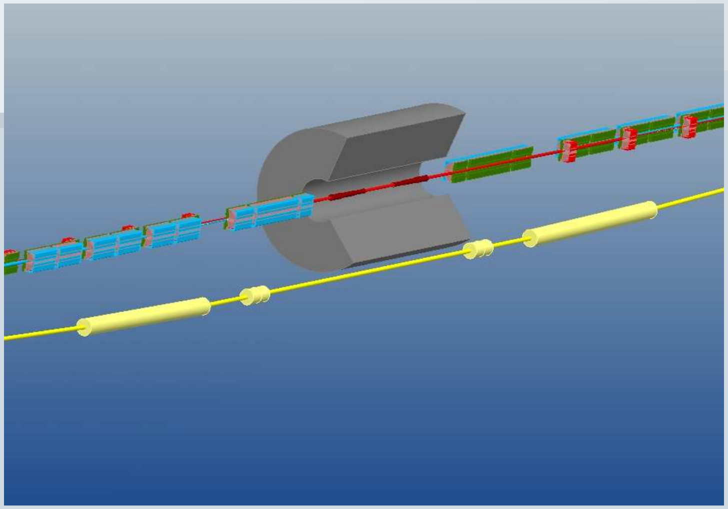
Polarization transparency (from the source to the IP) is realized by synchronous small (<40MeV) adjustment of energy gains ($\Delta\gamma_1$, $\Delta\gamma_2$) in small and large linacs.

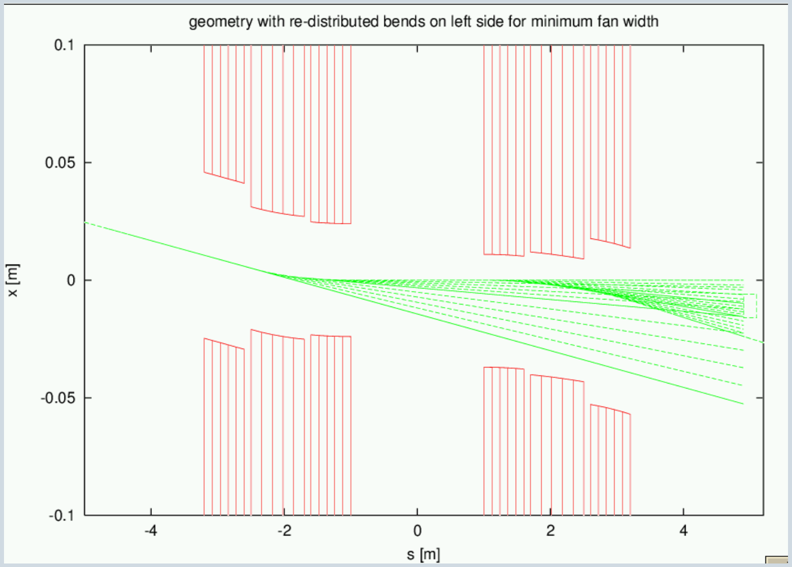
Superconducting RF Cavity

703.75 MHz 5-cell cavity
designed in BNL
for e-cooling and eRHIC

State-of-the-art cavity engineering design to minimize and damp High Order modes of electromagnetic field.

Interaction region design



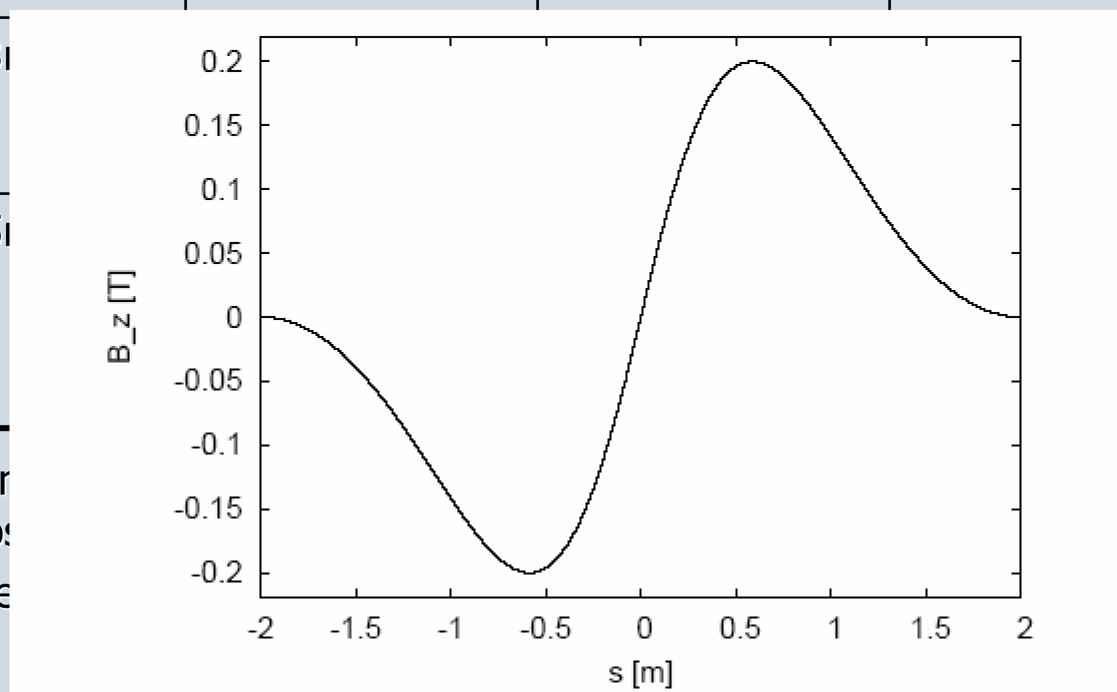


C.Montag, B.Parker, S.Tepikian, T.Zwart, D.Wang

- Design incorporates both warm and cold magnets.
- Provides fast beam separation. No parasitic collisions.
- Yellow ion ring makes 3m vertical excursion.
- Accommodates spin rotators and electron polarimeter.
- Put a limit on horizontal β^* for protons, because of aperture limitation in septum magnet, thus affecting achievable luminosity.
- Background produced by synchrotron radiation hitting septum magnet should not be problem (with HERA-like absrober used)

IR design schemes

	Distance to nearest magnet from IP	Beam separation	Magnets used	Hor/Ver beam size ratio
Ring-ring, l*=1m	1m	Combined field quadrupoles	Warm and cold	0.5
Ring-ring, l*=3m	3			
Linac-ring	5			



- l*=3m is preferable for ri
  acceptance. But at the co
- Detector integrated dipole

Luminosity for different options

- **Linac-Ring:**

$$L = \gamma_i \, f_c \, N_i \, \frac{\xi_i \, Z_i}{\beta_i^* \, r_i}$$

No electron beam-beam limit on ion current.

Luminosity is defined by ion beam parameters.

IR design allows for round beams at the collision point.

- **Ring-ring:**

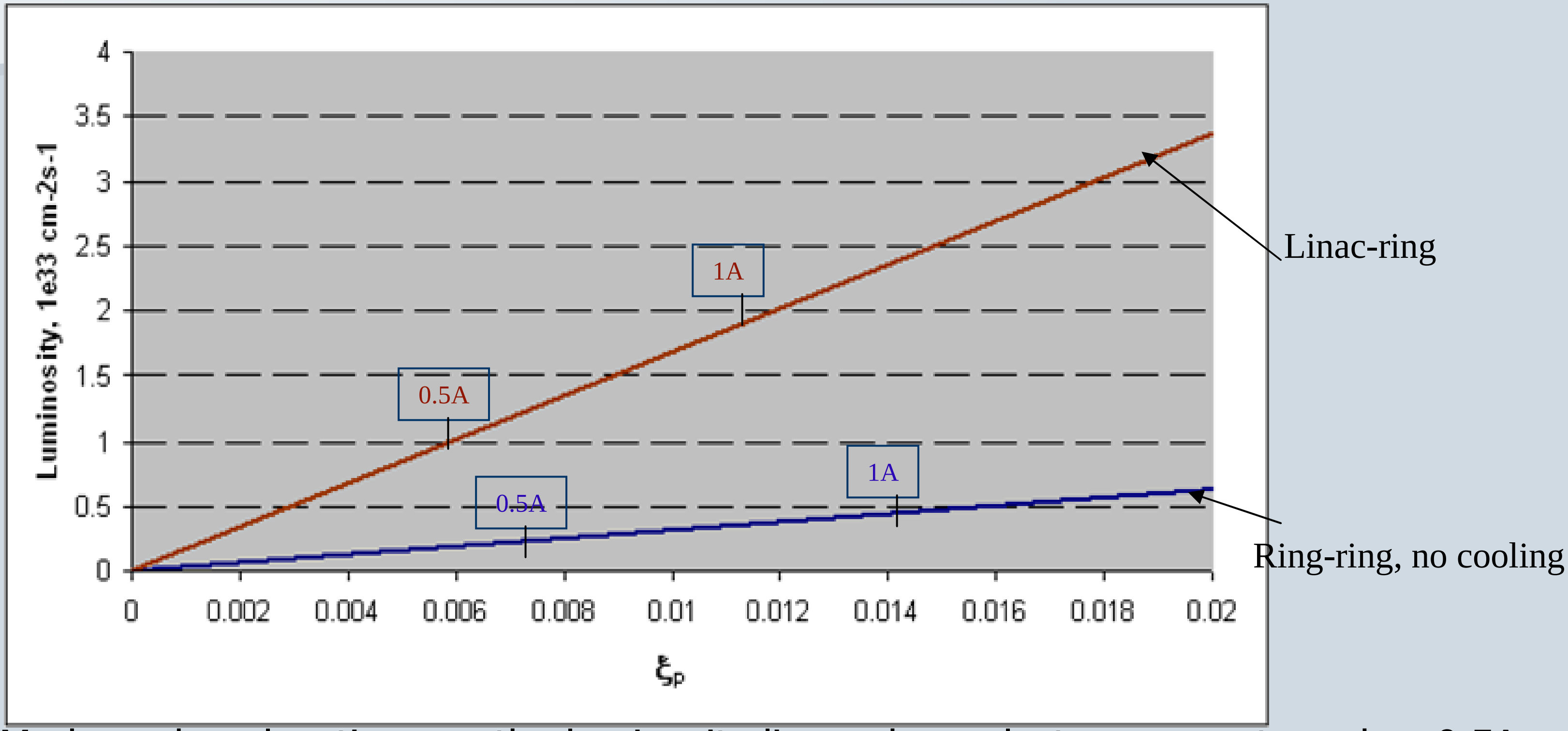
$$L = f_c \, \frac{\pi \gamma_i \gamma_e}{r_i r_e} \xi_{xi} \xi_{ye} \sigma'_{xi} \sigma'_{ye} k_e \, \frac{(1+K)^2}{K}$$

Limitation from IR design (septum magnet aperture) leads to elliptical beam (vertical to horizontal beam size ratio: K=1/2 and emittance ratio k_e~0.18) and the limit on σ'_{xi}

Electron beam-beam limit ($\xi_e < 0.08$) prevents proton intensity more than 1e11 p/bunch

Luminosity versus proton beam-beam parameter

Calculations for 360 bunch mode and 250 Gev(p) x 10 Gev(e) setup; 1e11 p/bunch

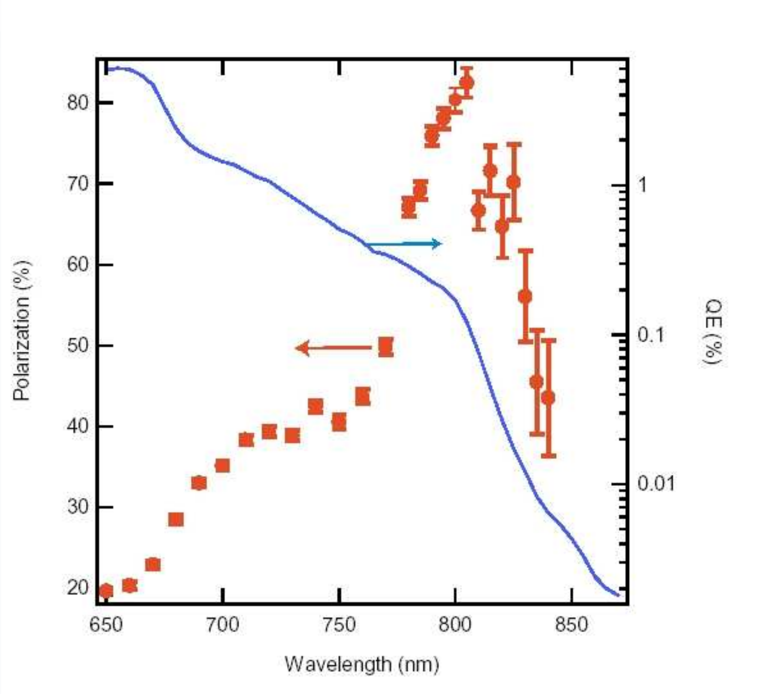


Markers show locations on the luminosity lines where electron current reaches 0.5A, which is presently nominal design current for both options.

In parallel mode (1 e-p + 2 p-p collision points): ξ_p~0.0065 (ε_p=15π mm*mrad) ;
In dedicated mode (only e-p collision): maximum ξ_p~0.016-0.018;

Electron Polarized Source

Photoemission from strained GaAs cathode



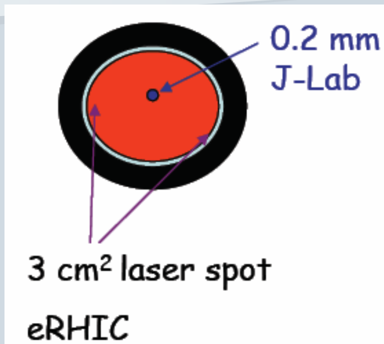
High polarization ->Low QE

- Present polarized CW sources:
  - Mainz: <100 μA
  - JLab(CEBAF):
    - 100 μA in routine operation
    - 200 μA (occasionally)
    - 1-2 mA (clear idea, plans for tests)
- eRHIC linac-ring requires several hundred mAs to go above 1.e33 luminosity

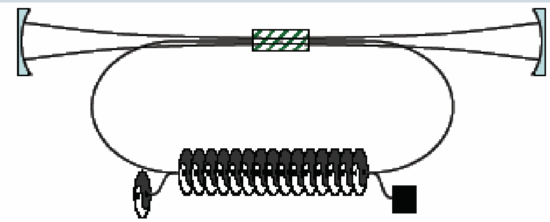
Major R&D is needed for the polarized electron source.

Electron Polarized Source -> development path

M.Farkhondeh, V.Litvinenko



circularly polarized
photon beam



Photon wavelength	850-750 nm
Polarization (left/right)	circular
Laser power [W]	1-2 kW
Mode of operation	CW
Rep-rate	28.15 MHz
μ-Pulse duration [ps]	100 - 200

Increase laser spots on the cathode,
maintaining moderate extracted charge
density per unit area.
Should provide sufficient target lifetime(~1 week).

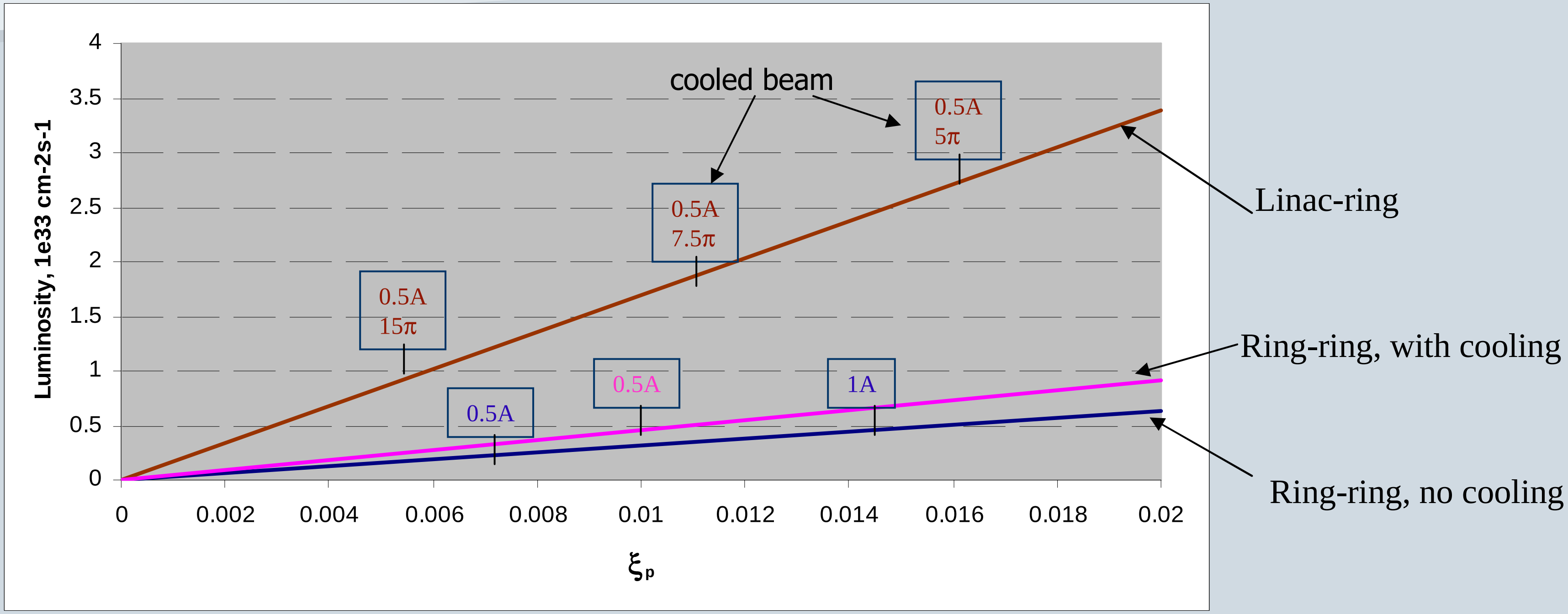
Free Electron Laser to provide sufficient
laser power
(unless common laser will develop to
the required power level of ~1kW)

Plenty of issues to overcome.
Major of them:
heat load and surface charge limit.

eRHIC polarized source R&D program in MIT-
Bates will explore those issues.

Luminosity with cooling

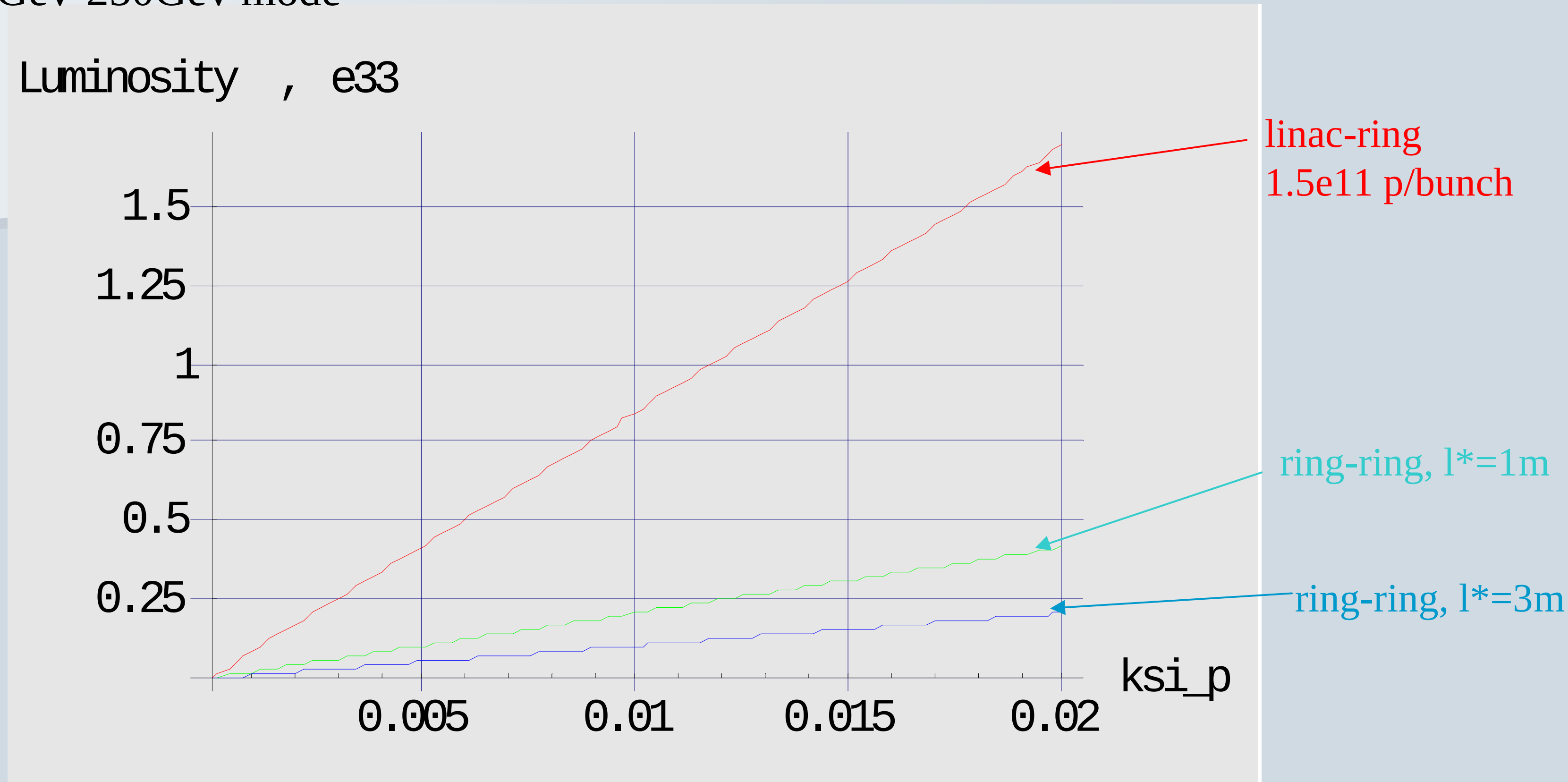
Calculations for 360 bunch mode and 250 Gev(p) x 10 Gev(e) setup; 1e11 p/bunch



Markers show electron current and (for linac-ring) normalized proton emittance.
In dedicated mode (only e-p collision): maximum ξ_p~0.016-0.018;

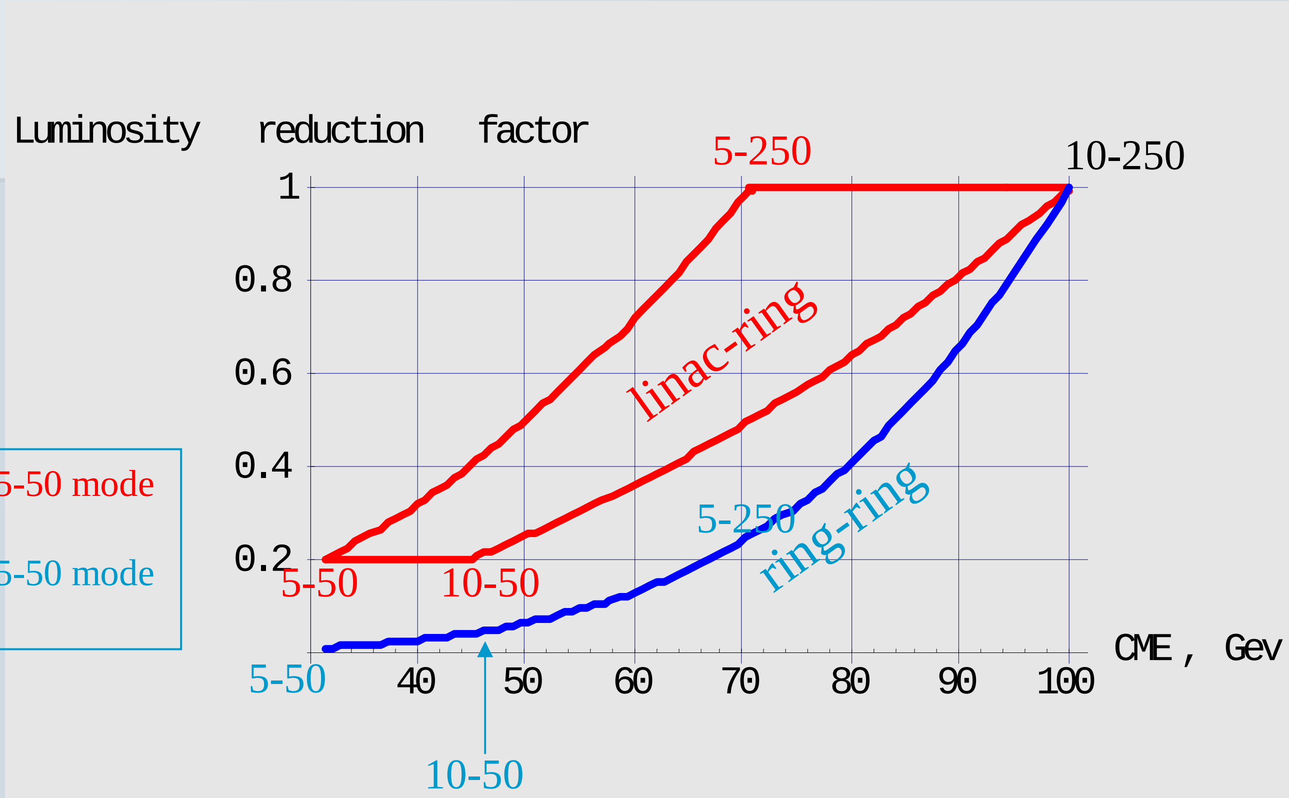
Transverse cooling can be used to improve luminosity or to ease requirements on electron source current in linac-ring option. BUT, only in dedicated mode!
For proton beam only cooling at the injection energy is possible at reasonable time (~1h)

e-p luminosity for 112 bunches and 15pi proton emittance
10Gev-250Gev mode



	Ksi_p	Ne per bunch, 1e11	Total electron current, A	Luminosity, 1e33
Linac-ring	0.0049	1	0.150	0.41
	0.012	2.46	0.37	1.01
Ring-ring l*=3m design	0.0065	1	0.150	0.07
	0.013	2	0.300	0.14

Luminosity dependence on CME without cooling



Luminosity reduction factor at 5-50 mode for linac-ring: 0.2
Luminosity reduction factor at 5-50 mode for ring-ring : 0.01.

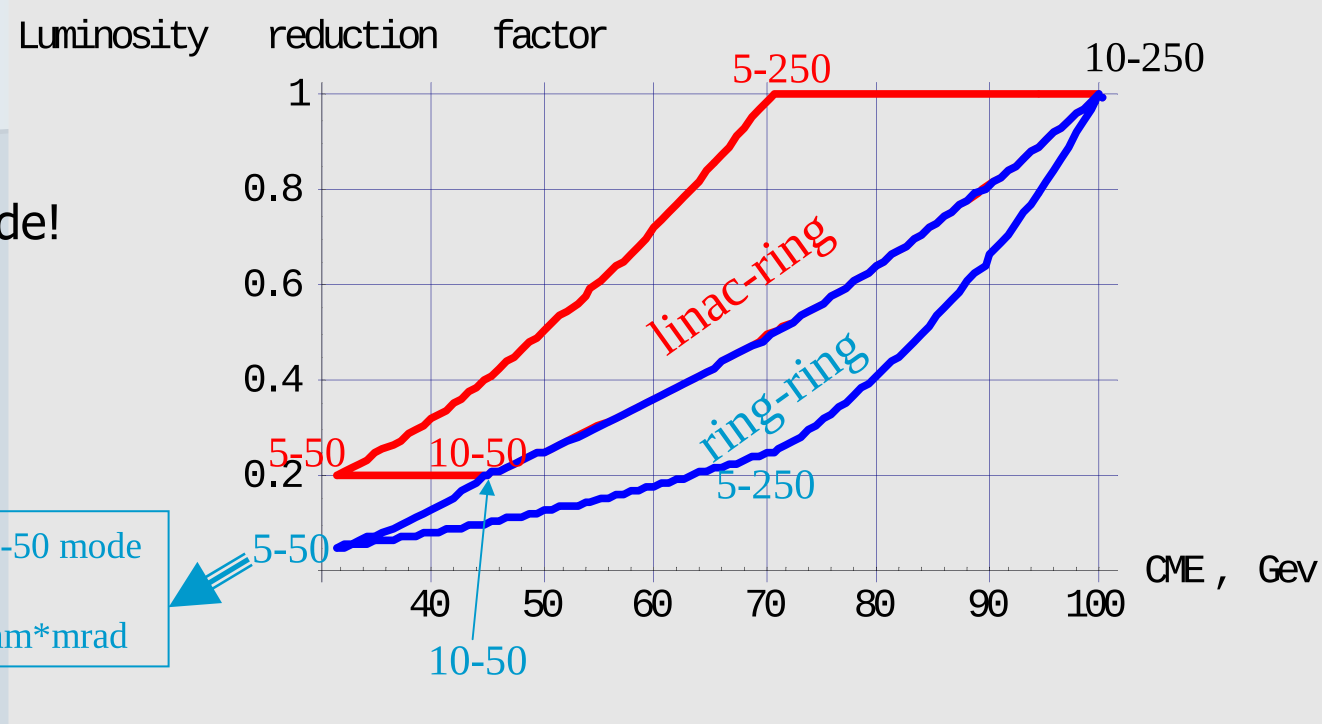
- Linac-ring optimal curve: **10-250 -> 5-250-> 5-50**

  This optimal curve requires electron beta* readjustment:

  β*(10-250) = 1m; β*(5-250) = 0.5m; β*(5-50) = 2.5m
- Ring-ring luminosity decreases as CME^{-4}.

Luminosity dependence on CME with cooling

Only in dedicated mode!



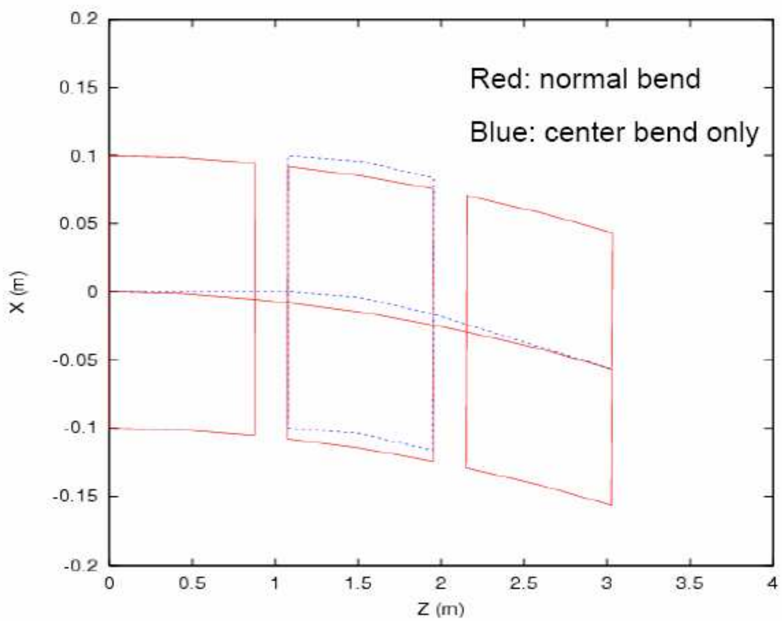
Luminosity reduction factor at 5-50 mode for ring-ring : 0.05.
Required norm.emittance ~3π mm*mrad

- For ring-ring the cooling improves luminosities for low energy proton modes. In this case optimal curve is: **10-250-> 10-50 -> 5-50**
- For linac-ring operation in proton beam-beam limit the cooling does not provide the luminosity increase, but can be used to unload (proportionally) required electron current. Optimal curve is: **10-250-> 5-250 -> 5-50**

Modular dipole

F.Wang

Example of a modular dipole for radiation enhancement at 5 GeV



	All bends on	Center bend on only
ρ (m)	70.3m	23.4
B(KG) 5GeV	2.37	7.12
P (MW)	~0.35	~1.06
τ_x (msec)	~54.5	~18.1

To increase beam-beam limit for 5Gev electrons the additional radiation damping should be created: special lattice with higher bending field at 5Gev

Alternative solution to enhance damping at 5Gev: dedicated damping wigglers

Major R&D issues

- **Ring-ring:**
  - The accommodation of synchrotron radiation power load on vacuum chamber. (To go beyond 5.e32 $cm^{-2}s^{-1}$ luminosity).
- **Linac-ring:**
  - High current polarized electron source
  - Energy recovery technology for high energy and high current beams
- **Ion ring:**
  - Beam cooling techniques development (electron, stochastic).
  - Increasing total current (ions per bunch and number of bunches).

    Going beyond 180 bunches will require cardinal injection system upgrade.
  - Polarized He^3 production (EBIS) and acceleration

Last notes

- Two design options for eRHIC are under development: ring-ring and linac-ring.
  - Zero-degree design has been produced (ZDR, 2004).
  - Present development is towards more detailed conceptual design report.

- Ring-ring design is at present level of accelerator technology, but e-p luminosity of 1.e33 $cm^{-2}s^{-1}$ is very difficult to achieve.

- At similar level of electron beam intensities the linac-ring design provides higher luminosity, but requires significant development for polarized electron source.
- Dedicated mode allows to exploit advantages of linac-ring option by using cooling and higher proton bunch intensity.